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BACTERIA ATTENUATED BY A NON-REVERTING MUTATION IN EACH OF THE AROC, OMPF AND OMPC GENES, USEFUL AS VACCINES

The invention relates to attenuated bacteria useful in vaccines.

Background to the invention

The principle behind vaccination is to induce an immune response in the host thus providing protection against subsequent challenge with a pathogen. This may be achieved by inoculation with a live attenuated strain of the pathogen, i.e. a strain having reduced virulence such that it does not cause the disease caused by the virulent pathogen.

Clasically, live attenuated vaccine strains of bacteria and viruses have been selected using one of two different methodologies. Mutants have been created either by treatment of the organism using mutagenic chemical compounds or by repeated passage of the organism *in vitro*. However, use of either method gives rise to attenuated strains in which the mode of attenuation is unclear. These strains are particularly difficult to characterise in terms of possible reversion to the wild type strain as attenuation may reflect single (easily reversible) or multiple mutation events. Furthermore, it is difficult to obtain such strains having optimum immunogenic properties because of multiple mutation events, and multiple strains may need to be used to provide protection against the pathogen.

Using modern genetic techniques, it is now possible to construct genetially defined attenuated bacterial strains in which stable attenuating deletions can be created. A number of site directed mutants of Salmonella have been created using this type of technology (2, 4, 5, 9, 12,

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16, 17, 18). Mutations in a large number of genes have been reported to be attenuating, including the aro genes (e.g. *aroA, aroC, aroD* and *aroE*), *pur, htrA, ompR, ompF, ompC, galE, cya, crp* and *phoP*.

Salmonella *aroA* mutants have now been well characterised and have been shown to be excellent live vaccines against salmonellosis in several animal species. In addition, in order to reduce the chances of a reversion to virulence by a recombination event, mutations have been introduced into two independent genes such as *aroA/purA* and *aroA/aroC*. Identical mutations in host adapted strains of Salmonella such as *S.typhi* (man) and *S.dublin* (cattle) has also resulted in the creation of a number of candidate single dose vaccines which have proved successful in clinial (8, 11) and field trials (10).

A *Salmonella typhimurium* strain harboring stable mutations in both *ompC* and *ompF* is described in Chatfield *et al* (1991, ref. 21). When administered orally to BALB/c mice the strain was attenuated, with the 50% lethal dose (LD50) reduced by approximately 1,000-fold. However, the intravenous LD50 was reduced only by approximately 10-fold, demonstrating the importance of the porins in confering on the bacteria the ability to infect by the oral route.

Expression of the *ompC* and *ompF* genes is regulated by *ompR*. Pickard *et al* (1994, ref. 13) describes the cloning of the *ompB* operon, comprising the *ompR* and *envZ* genes, from a *Salmonella typhi* Ty2 cosmid bank and characterisation by DNA sequence analysis. The DNA sequence data were used to identify appropriate restriction sites for generating a defined deletion of

517 bp within the open reading frame of the *ompR* gene. This deletion was introduced by homologous recombination into the chromosomes of two *S.typhi* strains which already harbored defined deletions in both the *aroC* and *aroD* genes. The *S.typhi ompR* mutants displayed a marked decrease in *ompC* and *ompF* porin expression as demonstrated by examination of outer membrane preparations. It was also shown that the *ompR-envZ* two component regulatory system plays an important role in the regulation of Vi polysaccharide synthesis in *S.typhi*.

In animal studies, attenuated *S.typhimurium* has been used as a vehicle for the delivery of heterologous antigens to the immune system (3, 6, 15). This raises the potential of the development of multivalent vaccines for use in man (7).

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Summary of the Invention

The invention provides a bacterium attenuated by a non-reverting mutation in each of the *aroC* gene, the *ompF* gene and the *ompC* gene. The invention also provides a vaccine containing the bacterium.

It is believed that the *aroC/ompF/ompC* combination of mutations gives a vaccine having superior properties. For example, it is believed that the *aroC/ompF/ompC* combination may be superior to a *aroC/ompR* combination for two reasons:

1. The *ompR* mutation may cause higher levels of attenuation than the *ompF/ompC* combination of mutations because *ompR* may regulate a number of genes other than *ompF* and *ompC* which are important for survival of the bacterium *in vivo*. Thus, the

ompF/ompC combination may allow the bacterium to survive in the vaccinated host for a longer time and at higher levels, resulting in better protection.

2. The *ompR* mutation may cause reduced immunogenicity compared to the *ompF/ompC* combination of mutations because *ompR* may regulate the expression of antigens important for immunogenicity.

Detailed Description of the Invention

Bacteria useful in the Invention

The bacteria that are used to make the vaccines of the invention are generally those that infect by the oral route. The bacteria may be those that invade and grow within eukaryotic cells and/or colonise mucosal surfaces. The bacteria are generally Gram-negative.

The bacteria may be from the genera Escherichia, Salmonella, Vibrio, Haemophilus, Neisseria, Yersinia, Bordetella or Brucella. Examples of such bacteria are *Escherichia coli* - a cause of diarrhoea in humans; *Salmonella typhimurium* - the cause of salmonellosis in several animal species; *Salmonella typhi* - the cause of human typhoid; *Salmonella enteritidis* - a cause of food poisoning in humans; *Salmonella choleraesuis* - a cause of salmonellosis in pigs; *Salmonella dublin* - a cause of both a systemic and diarrhoel disease in cattle, especially of new-born calves; *Haemophilus influenza* - a cause of meningitis; *Neisseria gonorrhoeae* - a cause of gonorrhoeae; *Yersinia enterocolitica* - the cause of a spectrum of diseases in humans ranging from gastroenteritis to fatal septicemic disease; *Bordetella*

pertussis - the cause of whooping cough; and *Brucella abortus* - a cause of abortion and infertility in cattle and a condition known as undulant fever in humans.

Strains of *E.coli* and Salmonella are particularly useful in the invention. As well as being vaccines in their own right against infection by Salmonella, attenuated Salmonella can be used as carriers of heterologous antigens from other organisms to the immune system via the oral route. Salmonella are potent immunogens and are able to stimulate systemic and local cellular and antibody responses. Systems for driving expression of heterologous antigens in Salmonella *in vivo* are known; for example the *nirB* and *htrA* promoters are known to be effective drivers of antigen expression *in vivo*.

The invention may be applied to enterotoxigenic *E.coli* ("ETEC"). ETEC is a class of *E.coli* that cause diarrhoea. They colonise the proximal small intestine. A standard ETEC strain is ATCC H10407.

Infections of ETEC are the single most frequent cause of travellers diarrhoea, causing 3-9 million cases per year amongst visitors to developing countries. In endemic areas, ETEC infections are an important cause of dehydrating diarrhoea in infants and young children, resulting in 800,000 deaths a year in the under fives world-wide. In developing countries, the incidence of ETEC infections leading to clinical disease decreases with age, indicating that immunity to ETEC infection can be acquired. In contrast, naive adults from industrialized countries who visit endemic areas are highly susceptible to ETEC infections. However, with prolonged or repeated visits to endemic areas susceptibility to ETEC infections diminishes, suggesting

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that a live attenuated approach to ETEC vaccination may prove successful.

The inventors chose to work on a non-toxigenic strain of ETEC called E1392/75/2A. E1392/75/2A arose spontaneously from a toxic mutant by deletion of toxin genes. In human studies, oral vaccination with live E1392/75/2A gave 75% protection against challenge with toxin-expressing ETEC from a different serotype. However, approximately 15% of vaccinees experienced diarrhoea as a side effect of the vaccine. The strain needs further attenuation to reduce the side effects before it can be considered as a potential vaccine and the invention gives a means of achieving such attenuation.

Seq Id No. 1 shows the sequence of the *E.coli aroC* gene, Seq Id No. 3 shows the sequence of the *E.coli ompC* gene and Seq. Id No. 5 shows the sequence of the *E.coli ompF* gene.

Further mutations

One or more further mutations may be introduced into the bacteria of the invention to generate strains containing mutations in addition to those in *aroC, ompC* and *ompF*. Such a further mutation may be (i) an attenuating mutation in a gene other than *aroC, ompC* and *ompF*, (ii) a mutation to provide *in vivo* selection for cells maintaining a plasmid (e.g. a plasmid expressing a heterologous antigen), or (iii) a mutation to prevent expression of a toxin gene.

The further attenuating mutation may be a mutation that is already known to be attenuating. Such mutations

include mutations in *aro* genes (e.g. *aroA, aroD* and *aroE), pur, htrA, ompR, galE, cya, crp, phoP* and *surA* (see e.g. refs 2, 4, 5, 9, 12, 13, 16, 17 and 18).

A mutation to provide selection for maintenance of a plasmid may be made by mutating a gene that is essential for the bacterium to survive. A plasmid carrying the essential gene is then introduced into the bacterium, so that only cells carrying the plasmid can survive. This may be useful where the plasmid contains, for example, a heterologous antigen to be expressed by the bacterium.

A mutation to prevent expression of a toxin gene may be made to reduce any side-effects caused by vaccination with the bacterium. For example, in the case of vaccination with *E.coli* strains such as ETEC it may be desirable to mutate the heat labile toxin (LT) or heat stable toxin (ST) genes so that they are not expressed.

The nature of the mutations

The mutations introduced into the bacterial vaccine generally knock-out the function of the gene completely. This may be achieved either by abolishing synthesis of any polypeptide at all from the gene or by making a mutation that results in synthesis of non-functional polypeptide. In order to abolish synthesis of polypeptide, either the entire gene or its 5'-end may be deleted. A deletion or insertion within the coding sequence of a gene may be used to create a gene that synthesises only non-functional polypeptide (e.g. polypeptide that contains only the N-terminal sequence of the wild-type protein).

The mutations are non-reverting mutations. These are mutations that show essentially no reversion back to the wild-type when the bacterium is used as a vaccine. Such mutations include insertions and deletions. Insertions and deletions are preferably large, typically at least 10 nucleotides in length, for example from 10 to 600 nucleotides. Preferably, the whole coding sequence is deleted.

The bacterium used in the vaccine preferably contains only defined mutations, i.e. mutations which are characterised. It is clearly undesirable to use a bacterium which has uncharacterised mutations in its genome as a vaccine because there would be a risk that the uncharacterised mutations may confer properties on the bacterium that cause undesirable side-effects.

The attenuating mutations may be introduced by methods well known to those skilled in the art (see ref. 14). Appropriate methods include cloning the DNA sequence of the wild-type gene into a vector, e.g. a plasmid, and inserting a selectable marker into the cloned DNA sequence or deleting a part of the DNA sequence, resulting in its inactivation. A deletion may be introduced by, for example, cutting the DNA sequence using restriction enzymes that cut at two points in or just outside the coding sequence and ligating together the two ends in the remaining sequence. A plasmid carrying the inactivated DNA sequence can be transformed into the bacterium by known techniques such as electroporation and conjugation. It is then possible by suitable selection to identify a mutant wherein the inactivated DNA sequence has recombined into the chromosome of the bacterium and the wild-type DNA sequence has been rendered non-functional by homologous

recombination.

Expression of heterologous antigens

The attenuated bacterium of the invention may be genetically engineered to express an antigen that is not expressed by the native bacterium (a "heterologous antigen"), so that the attenuated bacterium acts as a carrier of the heterologous antigen. The antigen may be from another organism, so that the vaccine provides protection against the other organism. A multivalent vaccine may be produced which not only provides immunity against the virulent parent of the attenuated bacterium but also provides immunity against the other organism. Furthermore, the attenuated bacterium may be engineered to express more than one heterologous antigen, in which case the heterologous antigens may be from the same or different organisms.

The heterologous antigen may be a complete protein or a part of a protein containing an epitope. The antigen may be from another bacterium, a virus, a yeast or a fungus. More especially, the antigenic sequence may be from *E.coli* (e.g. ETEC),tetanus, hepatitis A, B or C virus, human rhinovirus such as type 2 or type 14, herpes simplex virus, poliovirus type 2 or 3, foot-and-mouth disease virus, influenza virus, coxsackie virus or *Chlamydia trachomatis*. Useful antigens include non-toxic components of *E.coli* heat labile toxin, *E.coli* K88 antigens, ETEC colonization factor antigens, P.69 protein from *B.pertussis* and tetanus toxin fragment C.

The ETEC colonization factors and components thereof are prime candidates for expression as heterologous antigens. To instigate diarrhoeal disease, pathogenic strains of ETEC must be able to colonize the intestine and elaborate

enterotoxins. For most strains of ETEC colonization factors (CF) that are required for adhesion to the intestinal mucosa have been identified. In almost all cases CFs are expressed as fimbrae on the outer surface of the bacteria. A large number of CFs have been identified, the most prevalent being CFAI, CRAII (includes CS1, CS2, CS3) and CFAIV (includes CS4, CS5, CS6).

A vaccine to ETEC will ideally give protection against a range of colonization factor antigens to ensure that protection against different strains is obtained. In order to achieve this, it would be possible to express several colonization factors in one strain. Alternatively, the same attenuations could be made in a range of different ETEC strains, each with a different colonization factor. This would involve deleting the toxins from such strains.

The DNA encoding the heterologous antigen is expressed from a promoter that is active *in vivo*. Two promoters that have been shown to work well in Salmonella are the *nirB* promoter (19, 20) and the *htrA* promoter (20). For expression of the ETEC colonization factor antigens, the wild-type promoters could be used.

A DNA construct comprising the promoter operably linked to DNA encoding the heterologous antigen may be made and transformed into the attenuated bacterium using conventional techniques. Transformants containing the DNA construct may be selected, for example by screening for a selectable marker on the construct. Bacteria containing the construct may be grown *in vitro* before being formulated for administration to the host for vaccination purposes.

Formulation of the vaccine

The vaccine may be formulated using known techniques for formulating attenuated bacterial vaccines. The vaccine is advantageously presented for oral administration, for example in a lyophilised encapsulated form. Such capsules may be provided with an enteric coating comprising, for example, Eudragate "S" (Trade Mark), Eudragate "L" (Trade Mark), cellulose acetate, cellulose phthalate or hydroxypropylmethyl cellulose. These capsules may be used as such, or alternatively, the lyophilised material may be reconstituted prior to administration, e.g. as a suspension. Reconstitution is advantageously effected in a buffer at a suitable pH to ensure the viability of the bacteria. In order to protect the attenuated bacteria and the vaccine from gastric acidity, a sodium bicarbonate preparation is advantageously administered before each administration of the vaccine. Alternatively, the vaccine may be prepared for parenteral administration, intranasal administration or intramuscular administration.

The vaccine may be used in the vaccination of a mammalian host, particularly a human host but also an animal host. An infection caused by a microorganism, especially a pathogen, may therefore be prevented by administering an effective dose of a vaccine prepared according to the invention. The dosage employed will ultimately be at the discretion of the physician, but will be dependent on various factors including the size and weight of the host and the type of vaccine formulated. However, a dosage comprising the oral administration of from 10^7 to 10^{11} bacteria per dose may be convenient for a 70 kg adult human host.

Examples

The Examples described in this section serve to illustrate the invention.

Brief description of the drawings

Figure 1 shows a system for constructing defined deletions in target genes using splicing by overlay extension PCR mutagenesis.

Figure 2 shows the expected sequences of target genes after recombination and selection for deletions.

Figure 3 shows the cloning of deletion cassettes into plasmid pCVD442.

Figure 4 shows an SDS-PAGE analysis of outer membranes prepared from ETEC strains under conditions of low (no salt L-broth) and high (no salt L-broth + 15% sucrose) osmolarity. M = markers; Sample 1 = PTL010; Sample 2 = PTL002; Sample 3 = PTL003; Sample 4 = ΔaroCΔompC; Sample 5 = ΔompF.

Figure 5 shows expression of CS1 and CS3 in deletion strains after growth on CFA agar. Equal numbers of cells from each strain were loaded on a 15% SDS-PAGE gel and Western blotted with monospecific anti-CS1 or anti-CS3 polycional antibodies. Controls for antibody specificity were whole cesll lysates of TG1 cells expressing the majore pilin protein of CS1, or purified major pilin protein from CS3. Lane M, rainbow low molecular mass markers; lane 1, induced TG1 cells harbouring pKK223; lane 2, induced TG1 cells harbouring pKKCs1; lane 3, CS1-ETEC strain; lane 4, PTL010; lane 5, PTL001; lane 6, PTL002; lane 7, PTL003; lane 8, purified CS3 major pilin

protein.

Figure 6 shows a Southern blot of mutant loci. Chromosomal DNA was extracted from the wild-type ETEC (E1392/75-2A), PTL001 (htrA aroC), PTL002 (aroC ompR) and PTL003 (aroC ompC ompF) as indicated, digested with restriction endonuclease EcoRV, and pulsed field electrophoresed through 1% agarose. DNA was blotted from the gel onto Hybond N+ nylon membranes (Amersham) and hybridised with DNA probes derived from the aroC, htrA, ompR, ompC, or ompF loci as shown. The banding patterns are consistent with the mutant loci being deletions.

Figure 7 shows the IgA responses in volunteers administered a vaccine according to the invention.

EXAMPLE 1: CONSTRUCTION AND CHARACTERISATION OF STRAIN ACCORDING TO THE INVENTION

Design of deletions and construction of plasmids pCVD*ΔAroC*, pCVD*ΔOmpC* and pCVD*ΔOmpF*

Deletions were designated to remove the entire open reading frame of the target gene. Using the *E.coli* genome sequence as a template, PCR primers were designed to amplify fragments of 500-600 base pairs flanking the target open reading frame (see Table 1 for primer sequences). Splicing by overlap extension using PCR was used to fuse the two flanking sequences, creating a PCR product with the entire gene deleted (Figure 1). The wild-type sequences around the deletion site and the predicted sequences after deletion are depicted in Figure 2.

For each gene two different restriction sites were

introduced into the splice region (see Table 2 below). These were used for identification of deletion clones. The PCR primers at either end of the PCR fragment introduced unique restriction sites that were used to clone the fragment into the multiple cloning site of pCVD442 (Figure 3).

PCR products were gel purified using a Qiagen (Trade Name) gel extraction kit and digested with the relevant restriction enzymes prior to ligation to the suicide plasmid pCVD442(22) digested with the same enzyme and treated with alkaline phosphatase to prevent vector self-ligation (Figure 3). The ligation mix was transformed into SY327λ*pir* and plated on L-Ampicillin (100 µg/ml) plates. Plasmids from Ampicillin resistant transformants were screened for the presence of the deletion cassettes by restriction digestion. The following plasmids were generated:

pCVDΔ*AroC*
pCVDΔ*OmpC*
pCVDΔ*OmpF*

The suicide plasmid pCVD442 can only replicate in cells harboring the *pir* gene. On introduction into *non-pir* strains, pCVD442 is unable to replicate, and the Ampicillin resistance conferred by the plasmid can only be maintained if the plasmid is integrated in the chromosome by a single homologous recombination event. The plasmid also has a *sacB* gene, encoding levan sucrase, which is toxic to gram negative bacteria in the presence of sucrose. This can be used to select clones that have undergone a second recombination event, in which the suicide plasmid is excised. Such cells will be resistant to sucrose, but Ampicillin sensitive.

Construction and characterisation of *ΔAroCΔOmpCΔOmpF* strain

This section outlines the chronology of construction and history of a *ΔAroCΔOmpCΔOmpF* strain. In the section, "ETEC" refers specifically to strain E1392/75/2A or its derivatives.

ΔAroCΔOmpCΔOmpF deletions were introduced into E1392/75/2A in the following order:
ΔAroC→ΔAroCΔOmpC→ΔAroCΔOmpCΔOmpF

Construction of ETEC*ΔAroC*

1) E1392/75/2A from original microbanked stock was plated onto L-Agar.
2) Electroporation competent cells were prepared from these cells. 100 µl aliquots were frozen.
3) pCVD*ΔAroC* was purified from SY327*pir* cells using a Qiagen Qiafilter (Trade Name) midiprep. The plasmid was concentrated about 10-fold by ethanol precipitation. The construction of pCVD*ΔAroC* is described above.
4) 5 µl of concentrated plasmid was mixed with 100 µl defrosted cells and electroporated. The whole transformation was plated on an L-Ampicillin plate (50 µg/ml) and incubated overnight at 37°C.
5) A single Ampicillin resistant colony grew.
6) The colony was streaked onto an L-Ampicillin plate (100 µg/ml) and grown overnight at 37°C ("merodiploid plate").
7) PCR using primers TT19 and TT20 (specific for the *aroC* gene) and a colony picked from the merodiploid plate amplified two bands, with sizes corresponding to that of the wild-type and *ΔaroC* genes. The sequences of the primers are shown in Table 1

below.

8) A colony from the merodiploid plate was grown up for 7 hr in a) L-Ampicillin broth (100 µg/ml) and b) L-Broth. The colony grown on L-Ampicillin was microbanked.

9) Serial dilutions of the L-broth culture were set up on:

a) No salt L-agar

b) No salt L-agar + 5% sucrose.

The plates were incubated overnight at 30°C.

10) Colony counts showed that 10^4 more colonies grew on L-agar than on L-agar + 5% sucrose, showing sucrose selection worked.

11) Sucrose resistant colonies were screened for the presence of *ΔaroC* gene by PCR. Colonies chosen for screening were picked onto an L-agar plate and grown overnight at 37°C. This plate was stored at 4°C, whilst further tests were carried out.

12) 50% of 90 colonies tested had *ΔaroC* only.

13) Colonies were tested for growth on:

a) M-9 minimal media plates

b) M-9 minimal media + Aromix plates

c) L-Amp (100 µg/ml)

ΔaroC colonies should not grow on M-9 minimal media without Aromix or on L-Amp.

Aromix is a mix of aromatic compounds as follows:

Substance	Final concentration (% w/v)
Phenylalanine	0.004
Tryptophan	0.004
Tyrosine	0.004
p-aminobenzoic acid	0.001
dihydroxybenzoic acid	0.001

These compounds are made in wild-type bacteria, but the *aroC* mutation prevents their synthesis.

14) 13/14 putative ΔAroC colonies required Aromix for growth on M-9 minimal media and were susceptible to Ampicillin.

15) 3 colonies (No. 1,2,3) were tested for the presence of the CS1 major pilin protein gene by PCR using primers MGR169 and MGR170. All 3 colonies gave PCR products of the expected size (700 bp.). The sequences of the primers are shown in Table 1.

16) Colonies 1, 2 and 3 from screening master plate were streaked onto L-Agar and grown overnight at 37°C. Cells from these plates were used to inoculate microbank tubes.

17) Colony 1, stored in a microbank, was used for further work.

18) For permanent storage, a bead from the microbank tray was inoculated into 1 ml L-broth, grown for 4 hr with shaking at 37°C and used to make agar slopes which were used to make freeze dried stocks. The freeze dried stock of E1392/75/2A*ΔAroC* was designated PTL004. 20 ml of L-broth was added to the rest of the 1 ml culture and the culture was incubated overnight at 30°C. 1 ml of the overnight culture was transferred to each of three cryovials and stored in liquid nitrogen.

Construction of ETEC*ΔAroCΔOmpr*

1) Preparation of pCVD*ΔOmpC* plasmid DNA for electroporation:

A colony of SY327λ*pir* harbouring pCVD*ΔOmpC* was grown overnight at 37°C in 100 ml L-Ampicillin broth (100 µg/ml). Plasmid DNA was purified using 2 Qiagen Qiafilter (Trade Name) midipreps. DNA was

further concentrated by ethanol precipitation. The construction of pCVD*ΔOmpC* is described above.

2) Preparation of electrocompetent cells:
ETEC*ΔAroC* cells from the microbank tray produced in step 17 of the preceding section were streaked on L-agar, grown at 37°C overnight and then stored at 4°C for no more than 1 week before being used to inoculate cultures for preparing electrocompetent cells.

3) ETEC*ΔAroC* cells were electroporated with 5 µl of concentrated pCVD*ΔOmpC* DNA, and each transformation plated on a single L-Ampicillin plate (50 µg/ml) and grown overnight at 37°C.

4) 17 Ampicillin resistant colonies (putative ETEC*ΔAroC*/ pCVD*ΔOmpC* merodiploids) were obtained.

5) These colonies were spotted onto a master L-Ampicillin (100 µg/ml) plate and used as templates for PCR with primers TT7/TT8. The master plate was grown at room temperature over the weekend. The sequences of the primers are given in Table 1 below.

6) A single colony (No. 7) had the *ΔompC* gene.

7) The colony was grown for 5 hr in L-broth.

8) Serial dilutions of the L-broth culture were set up on:

   a) No salt L-agar

   b) No salt L-agar + 5% sucrose.

The plates were incubated overnight at 30°C.

9) Colony counts showed that 10^4 more colonies grew on L-agar than on L-agar + 5% sucrose, showing sucrose selection worked.

10) 45 sucrose resistant colonies were screened for *ΔompC* by PCR using primers TT7 and TT8. 9 colonies had the *ΔompC* gene, but most had traces of w.t. *ompC gene*. The sequences of the primers are given

in Table 1 below.

11) To further characterise putative ETECΔAroCΔOmpC colonies, they were grown in 1 ml L-Broth for 5 hr and plated on:

a) L-Agar + 100 µg/ml Ampicillin

b) L-Agar

c) L-Agar + 5% sucrose

ΔOmpC colonies should be resistant to sucrose and sensitive to Ampicillin.

12) Only 1 colony (No. 1) was Ampicillin sensitive and sucrose resistant.

13) Colony 1 was checked for the presence of *ΔaroC, ΔompC* and CS1 genes by PCR with primers TT19/TT20, TT7/TT8 and MGR169 and 170. The sequences of the primers are given in Table 1 below.

14) Colony 1 gave single PCR products of the expected size for *ΔaroC, ΔompC* and CS1 genes.

15) The colony was microbanked.

16) For permanent storage, a bead from the microbank was inoculated into 1 ml L-broth, grown for 4 hr with shaking at 37°C and used to make agar slopes which were freeze dried. The freeze dried stock of E1392/75/2A*ΔaroCΔOmpC* was designated PTL008. 20 ml of L-broth was added to the rest of the 1 ml culture and the culture was incubated overnight at 30°C. 1 ml of the overnight culture was transferred to each of three cryovials and stored in liquid nitrogen.

Construction of ETECΔ*aroCΔOmpCΔOmpF*

Conjugation was used to introduce pCVD*ΔOmpF* into E1392/75/2A*ΔaroCΔOmpC*.

1) Conjugation donor cells SM10λ*pir* were transformed with pCVD*ΔOmpF*. The construction of plasmid

pCVDΔ*OmpF* is described above.

2) ETECΔ*AroC*Δ*OmpC* cells were conjugated with SM10λ*pir*/ pCVDΔ*OmpF* cells. The pCVD442 plasmid includes a transfer origin which allows the plasmid to be transferred from a donor strain containing the RP4 transfer genes (e.g. SM10λpir) to a recipient strain (e.g. ETEC). ETECΔ*aroC*Δ*ompC* cells and *E.coli* strain SM10λ*pir* harbouring the PcvdΔompF recombinant were cross-streaked on L-agar plates so as to cover an area of approximately 10 cm^2. Plates were incubated at 37° C for 20 h, then the growth washed off using 4 ml L-broth and the suspension plated onto McConkey agar (Difco) containing streptomycin at 20μg ml^{-1} and ampicillin at 300μg ml^{-1}. Plates were incubated overnight at 37°C and resulting colonies were checked for merodiploidy by PCR using appropriate oligonucleotides as primers.

3) Putative ETEC transconjugants were screened. 10 colonies were picked from McConkey agar plates and grown overnight on L-Ampicillin (100 µg/ml) agar. The presence of Δ*ompF* gene was checked for by PCR with primers TT1/TT2. The sequences of the primers are given in Table 1 below.

4) The colonies were grown for 5 hr in L-broth.

5) Serial dilutions of the L-broth culture were set up on:

   a) No salt L-agar

   b) No salt L-agar + 5% sucrose.

The plates were incubated overnight at 30°C.

6) Colony counts showed 10^5 more colonies grew on L-agar than on L-agar + 5% sucrose, showing sucrose selection worked.

7) Sucrose resistant colonies were screened for Δ*ompF* gene by PCR with primers TT1/TT2. The sequences of

the primers are given in Table 1 below. The screened colonies were grown overnight on L-Agar. 3 colonies out of 47 had the *ΔompF* gene with no evidence of the wild-type *ompF* gene.

8) To further characterise putative ETEC*ΔAroCΔOmpCΔOmpF* colonies, they were plated on:

a) L-Agar + 100 µg/ml Ampicillin

b) L-Agar

c) L-Agar + 5% sucrose

ΔompF colonies should be resistant to sucrose and sensitive to Ampicillin.

9) All three *ΔompF* colonies were Ampicillin sensitive and sucrose resistant.

10) The colonies were microbanked and one colony was chosen as a master stock.

11) For permanent storage, a bead from the master stock was inoculated into 1 ml L-broth, grown for 4 hr with shaking at 37°C and used to make agar slopes which were used to make freeze dried stocks. The freeze dried stock of E1392/75/ 2A*ΔaroCΔompCΔompF* was designated PTL003. 20 ml of L-broth was added to the rest of the 1 ml culture and the culture was incubated overnight at 30°C. 1 ml of the overnight culture was transferred to each of three cryovials and stored in liquid nitrogen.

Characterisation of E1392/75/2A*ΔAroCΔOmpCΔOmpF*

1) Growth requirements:

Cells taken from the master stock produced in step 10 of the preceding section were streaked on L-Agar plate. At the same time 8 ml L-broth was inoculated for a chromosomal DNA prep for Southern blots. Both plate and liquid culture were grown overnight at 37°C.

Cells from the grown plate were streaked onto the

following media and grown overnight at 37oc.

Medium	Growth
L-Amp	No
M9 minimal media	No
M9 minimal + Aromix	Yes
M9 + sulfathiazole (100 µg/ml)	No
M9 + sulfathiazole (100 µg/ml) + Aromix	Yes
L-Agar + 50 µg/ml streptomycin	Yes
L-Agar + 5% sucrose	Yes

As expected, the cells were Amp sensitive. The cells were resistant to sucrose, streptomycin and sulfathiazole, but required Aromix to grow on minimal media.

2) LPS analysis of PTL003:

a) A freeze dried vial of PTL003 was broken open. The culture was resuspended in L-Broth and plated on L-Agar for growth. Some cells were scraped off and stored in microbank.

b) More cells were scraped off and the LPS profile was analysed. There was no visible difference between the LPS profile of PTL003 and original E1392/75/2A strain.

3) Confirmation of deletions by PCR:

a) A scrape of cells was taken from the plate made in in 2a and streaked onto L-Agar and grown overnight.

b) Freshly grown cells were used for PCR with primers that flank the following genes: *aroC, htrA, ompC, ompF, ompR*.

c) PTL003 was shown to have deletions in *aroC,*

ompC and *ompF* genes, but not in *htrA* or *ompR*.

4) Analysis of outer membrane protein profile of PTL003:

Outer membrane protein fractions were prepared from strains PTL010 (E1392/75/2A) and the deletion strains PTL002 and PTL003. A strain with a single *ompF* deletion and a strain with both *aroC* and *ompC* deletion were also analysed. Strains were grown under conditions of low osmolarity (no salt L-broth) and high osmolarity (no salt L-broth+15% sucrose). The OmpF protein product is normally expressed at low osmolarity whereas the OmpC product is expressed at high osmolarity. The OmpC and OmpF proteins have similar electroporetic mobilities. At both high and low osmolarities, the strain PTL003 lacks proteins in the OmpC/OmpF region when compared to the wild-type E1392/75/2A strain or to the ΔAroCΔOmpC or ΔOmpF deletion strains. The results are shown in Figure 4.

5) Expression of CS1 and CS3 pili on CFA agar:

The expression of CS1 and CS3 pili in the deletion strains was examined. Equal numbers (2 A_{600nm} units) of bacteria strains PTL010, PTL001, PTL002 and PTL003 grown overnight at 37°C on CFA agar were subjected to SDS PAGE and analysed by Western blotting with monospecific polyclonal antibodies against CS1 or CS3. CS1 and CS3 pili were expressed equally well in four strains (Figure 5).

A CFAII-negative derivative of E1392/75/2A was constructed for use as a control. This was done by specific curing of the CS encoding plasmids from ETEC strain E1392/75-2A. A short fragment of DNA was amplified from the *cooB* gene using PCR with

oligonucleotides CSA01 and CSA02 as primers and ligated into pGEM-T Easy plasmid vector (Trade Name, Promega) designed for the cloning of PCR products. The fragment was subcloned into pCVD442 by virtue of the *Sal*I and *Sph*I restriction enzyme sites. The pCVD442-*cooB* derivative was introduced into ETEC strain E1392/75/2A by conjugation from SM10λ*pir*. Ampicillin resistant transconjugants are most likely to be the result of fusion of the pCVD442-*cooB* derivative with *cooB*-bearing plasmid. Such transconjugates were then grown on L-agar supplemented with 5% sucrose to select for loss of the sacB gene of pCVD442. Resulting colonies were tested for ampicillin sensitivity, and by PCR using CSA01 and CSA02 as primers. Three colonies of E1392/75/2A were included as positive controls among these PCRs. Two sucrose resistant colonies that gave no product with the PCR were streaked out onto fresh L-agar supplemented with 5% sucrose to obtain pure cultures. These were then grown in L-broth at 37°C for approximately 16 h and microbanked at -70°C. Loss of the CS1 encoding plasmid was confirmed by analysis of the plasmid profiles of the derivatives using agarose gel electrophoresis. Two derivatives were confirmed as CS1 negative, but were still CS3+.

6) Southern blotting of PTL003:
Structure of deletion mutations. Total DNA was extracted from cultures of the three deletion mutants grown from the microbanked stocks, digested with restriction endonuclease *Eco*RV, and the digested DNA subjected to pulsed field agarose gel electrophoresis. DNA was blotted from the gels onto Hybond N+ (Trade Name) nylon membranes and

hybridised with appropriate DNA probes according to standard procedures. Results (Figure 6) show that the hybridising chromosomal DNA fragments of the mutants are shorter than the wild-type, consistent with the mutations being deletions.

Confirmation of absence of Heat-Stable (ST) and Heat-Labile (LT) toxin genes in E.coli strain E1392/75-2A. For this the ST and LT-AB genes were used as DNA probes against total DNA from E1392/75-2A. Total DNA from the toxin positive ETEC strain E1393/75 was included as a positive control, while that from the laboratory *E.coli* strain JM109 was included as a negative. Hybridised membranes were left under Hyperfilm-ECL (Trade Name) for 1 h to obtain the maximum amount of signal. Probes were prepared using PCR with plasmid DNA extracted from E1392/75-2A as template and oligonucleotides EST01 and EST02 as primers for ST, or LT-R1 and LT-03 for LT-AB. There was no significant hybridisation with total DNA using either the LT-AB or the ST probe, despite obtaining a very intense signal from the positive control total DNA.

Confirmation of absence of pCVD442 sequences from the chromosome of deletion mutants. The plasmid pCVD442 was labelled and hybridised to total DNA from deletion mutants PTL001, PTL002 and PTL003 digested with *Eco*RV. Total DNA from ETEC strain E1392/75-2A was included as a control. A complex pattern of hybridising DNA fragments was obtained. But, there was no significant difference between the pattern obtained for the wild-type and that for the mutants, indicating that probably no residual pCVD442 nucleotide sequences were left in the genomes of the mutants. The complex pattern of

hybridising fragments was most likely due to the pCVD442 probe hybridising with the plasmid DNA components of the E1392/75-2A strain and mutant derivatives.

Table 1 - PCR primers

Name	Target	Use	Sequence (5'-3')
TT1	*ompF*	Primer A for cloning	ATC TGT TTG TTG AGC TCA GCA ATC TAT TTG CAA CC
TT2	*ompF*	Primer B for cloning	TTT TTT GCC AGC ATG CCG GCA GCC ACG CGT AGT G
TT3	*ompF*	Primer C for cloning	CTC GAG GCT TAG CTC TAT TTA TTA CCC TCA TGG
TT4	*ompF*	Primer D for cloning	GAG CTA AGC CTC GAG TAA TAG CAC ACC TCT TTG
TT7	*ompC*	Primer A for cloning	TTG CTG GAA AGT CGA CGG ATG TTA ATT ATT TGT G
TT8	*ompC*	Primer B for cloning	GGC CAA AGC CGA GCT CAT TCA CCA GCG GCC CGA CG
TT9	*ompC*	Primer C for cloning	GCT AAG CCT CGA GTA ATC TCG ATT GAT ATC CG
TT10	*ompC*	Primer D for cloning	CTC GAG GCT TAG CGT TAT TAA CCC TCT GTT A

TT19	*aroC*	Primer A for cloning	CCG CGC TCG CTC TAG AGT GAA CTG ATC AAC AAT A
TT20	*aroC*	Primer B for cloning	ATG CGC GCG AGA GCT CAA CCA GCG TCG CAC TTT G
TT21	*aroC*	Primer C for cloning	CTC GAG GCA TGC TGA ATA AAA CCG CGA TTG
TT22	*aroC*	Primer D for cloning	GCA TGC CCT CGA GGG CTCC GTT ATT GTT GTG
MGR169	CS1	Binds in CS1 sequence	TGA TTC CCT TTG TTG CGA AGG CGA A
MGR170	CS1	Binds in CS1 sequence	ATT AAG ATA CCC AAG TAA TAC TCA A
LT-R1	LT-AB	See text	GCT TTT AAA GGA TCC TAG TT
LT-03	LT-AB	See text	GGT TAT CTT TCC GGA TTG TC
EST01	ST	See text	CAT GTT CCG GAG GTA ATA TGA A
EST02	ST	See text	AGT TCC CTT TAT ATT ATT AAT A
CSA01	CS1	See text	TGG AGT TTA TAT GAA ACT AA
CSA02	CS1	See text	TGA CTT AGT CAG GAT AAT TG
CS3-01	CS3	See text	ATA CTT ATT AAT AGG TCT TT
CS3-02	CS3	See text	TTG TCG AAG TAA TTG TTA TA

Table 2

Target gene	Sites used for cloning into pCVD442		Sites introduced for screening purposes	
	Site 1	Site 2	Site 3	Site 4
aroC	XbaI	SacI	XhoI	SphI
htrA	SalI	SphI	XhoI	XbaI
ompC	SalI	SacI	BlpI	XhoI
ompF	SacI	SphI	BlpI	XhoI
ompR	SalI	SacI	BlpI	SphI

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EXAMPLE 2: SAFETY AND IMMUNOGENICITY OF ATTENUATED VACCINE STRAIN OF ENTEROTOXIGENIC *E. COLI* (*ΔaroC/ΔompC/ΔompF*) IN HUMAN VOLUNTEERS

The study was designed to evaluate a candidate live attenuated vaccine strain of enterotoxigenic *E. coli*, namely the *ΔaroC/ΔompC/ΔompF* PTL003 described above.

Preparation of the vaccine seed lots

The bacterial strain was plated onto MacConkey agar for purity and for confirmation of identity, and 5 colonies used to inoculate a flask containing 200 ml of luria broth. After 8 hours incubation at +37°C, 30 ml of sterile glycerol was added to the broth culture and aliquots prepared (1 ml per vial). One hundred such vials were frozen at -70°C. These vials constituted the seed lot for the vaccine strain.

Purity of the seed lot was ensured by selecting ten random vials, and testing them for bacterial purity and freedom from fungi. An additional three vials were tested to determine the number of bacteria in the vials using standard plate count methods with serial dilutions of the culture broth.

Preparation of the vaccine

The vaccine was prepared fresh prior to each vaccination and all steps in the preparation of the inoculum carried out in a safety cabinet. The day prior to vaccination, 0.2 ml was spread onto the surface of luria agar plates using sterile cotton swabs to prepare the lawn of bacteria. The same culture broth was streaked onto MacConkey and luria agar plates for purity. The agar plates were incubated at 37°C for 18 hours in a sealed container with tamper-resistant indicator tape to ensure that the plates were not tampered with during incubation. After incubation, the lawn of bacteria was harvested with 5 ml of sterile phosphate buffered saline (PBS), and the optical density of the suspension measured. The appropriate volume of this suspension, corresponding to the desired dose, was then placed into unit dose bottles with 30 ml of bicarbonate buffer and administered to the volunteers. An extra dose of vaccine was prepared and left in the laboratory, and immediately after the volunteers had been vaccinated the actual number of bacteria in each dose of vaccine was validated using standard colony count procedures with ten fold dilutions of vaccine.

The procedure for diluting the bacteria was established during preliminary studies using lawn cultures prepared and incubated exactly as done for the vaccine preparations administered to volunteers. Suspensions were made and the

number of viable bacteria enumerated by colony counts of serial dilutions and related to the determined optical density. Based on these preliminary studies, a standard procedure was developed for preparing and validating the correct dilutions of bacteria in order to give the doses stated.

Preparation of buffer

A buffer consisting of sodium bicarbonate in water was used. For each dose of vaccine 150 ml of deionised water containing 2 gram of sodium bicarbonate was prepared and filter sterilised. 30 ml of the buffer was placed into 50 ml sterile vials and the dose of vaccine bacteria was added to these vials. The remaining 120 ml of buffer was placed into separate sterile bottles. At the time of vaccination, the volunteers were first administered 120 ml of buffer, then a minute later, 30 ml of buffer containing the vaccine.

Vaccination schedule

Groups of volunteers were studied in a dose escalation manner. The first group of volunteers received a dose of approximately $5X10^7$ bacteria, the second a dose of approximately $5X10^9$ and the third group a dose of approximately $5X10^8$.

The volunteers were given Ciprofloxacin 500 mg BID for three days beginning on day 4. They were discharged on day 6, having had a haematology and chemistry screen for safety. Serum was saved for antibody measurement.

On days 9 and 14 the volunteers returned for follow-up outpatient visits at which time an interval history was

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done and a blood sample was obtained for serological assays. In total, blood (40 ml) was collected for serology three times, prior to vaccination and on day 9 and day 14 after vaccination.

Laboratory Assay Procedures

Up to two faecal specimens were cultured each day while the volunteers were in hospital. For qualitative cultures, a faecal swab was placed into Cary Blair transport media and taken to the laboratory where it was inoculated directly onto MacConkey agar and onto MacConkey agar containing antibiotics selective for the vaccine strain. Up to five colonies were shown to be agglutinated using antisera specific for the vaccine strain. For quantitative culture (first specimen each day only) faecal specimens were weighed and diluted in PBS, with serial 10-fold dilutions up to 10^{-4}, and then 100 µl of each dilution was spread onto MacConkey agar with antibiotics. Suspected colonies were confirmed by agglutination with anti-O serum.

Serum was collected and saved for subsequent assay for antibody against CFA II antigens by ELISA and bactericidal antibody against the vaccine strain.

Peripheral blood mononuclear cells were separated from whole blood collected into citrate and washed. These cells were cultured at a density of 10^7 cells per ml in RPMI tissue culture medium at 37°C for 48 hours. After 48 hours the supernatant was transferred to a cryovial and frozen at -20°C until it could be assayed for IgG and IgA antibody to CFA II by ELISA.

Table 3 - Summary of the procedures of the protocol

Day (Vaccination day is day 0)	pre	-1	0	1	2	3	4	5	6	9	14
Recruitment / screening	x										
HCG (urine)	x				x						
Training/ consent	x										
Inpatient stay		x	x	x	x	x	x	x	x		
Vaccination			x								
Outpatient visit	x									x	x
Stool cultures - quantitative		x	x	x	x	x	x	x	x	x	x
Stool cultures - qualitative		x	x	x	x	x	x	x	x	x	x
Serology		x								x	x
CBC/Chem panel	x								x		
Ciprofloxacin 500mg BID for 3d							x	x	x		

Results:

No symptoms were seen at all actual doses of 6.8×10^7 and 3.7×10^8 cfu. At the higher dose of 4.7×10^9 1/6 volunteers experienced diarrhoea and 2/6 had mild abdominal cramps. Bacterial shedding was seen in all volunteers at the $5X10^9$ cfu dose level form day 1 post vaccination until, as per protocol, ciprofloxacin was started on day 4 after vaccination. This indicates good intestinal colonisation, which is indicative of the potential to induce a good immune response. At the two lower doses, vaccine strain was recovered from all volunteers on at least one time point following vaccination but the duration of the excretion was reduced compared to that seen at the highest dose.

At the time of filing the application, the analysis of the immune responses generated by the vaccine was incomplete.

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However, the IgA anti-CFA II responses in the culture supernatants of PBMNC purified from the blood of recipients of the highest dose of vaccine at day 0 (before vaccination) and days 7 and 10 post vaccination have been analysed (see Figure 7). Supernatants were analysed by ELISA on assay plates coated with purified CFA II antigen. The OD values observed from the day 7 and day 10 samples were significantly higher than those from the pre-vaccination samples, demonstrating the induction of a specific IgA response at these time points. As expected, the responses show a peak at day 7 and are reduced at day 10, consistent with the homing of primed IgA secreting B-cells from the blood to the mucosal effector sites of the Gut Associated Lymphoid Tissue.

Conclusions:

The attenuated live strain of ETEC (ΔaroC/ΔompC/ΔompF) has been shown to be well tolerated in healthy adult volunteers and to colonise the intestine in a manner consistent with its utility as an oral vaccine to protect against travellers diarrhoea. It has also been demonstrated to elicit a specific mucosal immune response.

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